Italian Journal of Food Science, 2022; 34 (2): 9–20

Effect of high-moisture extrusion on soy meat analog: study on its morphological and physiochemical properties

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Received: 10 October 2021; Accepted: 7 December 2021; Published: 2 April 2022

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Abstract

There has been a growing interest in meat analog, microstructure characteristics, and anti-nutritional content obtained from soybean. High-moisture extrusion parameters are the input extruder of moisture content (>40%) that get the advantages of lower energy input. Thermo-mechanical treatment has a considerable influence on structural properties of soy-based meat analog. Texturized soy proteins can substitute meat products while providing a high-protein food ingredient which can be consumed directly as meat analogs. Therefore, this review aims to the effect on soybean of micro-structural and physicochemical properties of meat analogs by high-moisture extrusion. Thus, further studies are required concerning a large-scale meat products with purify protein structure.

Keywords: soy meat analog; high-moisture extrusion; allergenic protein; anti-nutritional factors; textural properties

Introduction

Soybean (*Glycine max*), which has its origin in East Asia (especially in China and Japan), belongs to the legume family (Kader *et al*., 2017). It is an excellent alternative source of proteins, complex carbohydrates, polyunsaturated fatty acids, soluble fibers, and isoflavones. Nowadays, it's grown worldwide as an edible bean (Peluso *et al*., 2014). Wang *et al*. (2020) reported that 60 varieties were used for the product development by 2018; 398 million tons of soybeans were produced worldwide, with 61% for oilseed production. In addition, Salgado and Donado-Pestana (2011) found that 90% of the total soybean production in the world is from the United States of America (USA), Brazil, South America, and Northwestern Europe. Moreover, Jooyandeh (2011) reported soybean oil composition that is 15% saturated, 61% polyunsaturated, and 24% monounsaturated fats. Furthermore, Fiala (2008) described that by 2030, the increase in the population, industrialization, and urbanization will also increase the plant meat demand by about 72%.

Golbitz and Jordan (2006) found that soybeans typically contain 35–40% proteins with well-balanced amino acid composition, 30% carbohydrate, 15–20% fat, 10–30% moisture content as well as fiber, calcium (Ca), iron (Fe), zinc (Zn), and vitamin B complex. The nutritional composition of soybean/legume is presented in Table 1. In addition, soybean contains some minor compounds, such as lecithin, isoflavones, bio-peptides, and others, that are effective against chronic cancer, cardiovascular diseases, and type II diabetes (Dixit *et al*., 2011; Singh, 2010; Singh *et al*., 2008). Soybean protein is suitable for people, who lack plant protein, for nutritional value and

Table 1. Nutritional composition of plant based protein, Quorn protein and microbial proteins legume.

Protein source	Protein content	Mineral content	References
Legume protein	Legume seed (20–30%)	–	(Riascos *et al.*, 2010)
	–	Soy protein (concentrate): Potassium (2.4%), Phosphorus (0.9%), Calcium (0.4%), Magnesium (0.3), Iron (0.02%), Zinc (0.005%)	(Singh *et al.*, 2008)
Oilseed protein	Safflower seed (13–17%)	–	(Asgar *et al.*, 2010)
	Cottonseed (23%)	–	
	Rapeseed (25%)	–	
	Gourd seed	Calcium (0.055%), Magnesium (0.720%), Potassium (0.965%), Iron (0.021%), Zinc (0.016%)	(Olaofe *et al.*, 1994)
	Pumpkin seed	Calcium (0.072%), Magnesium (0.778%), Potassium (1.127%), Iron (0.027%), Zinc (0.017%)	(Olaofe *et al.*, 1994)
Cereal protein	Maize (8.8–11.9%)	–	(Orcutt *et al.*, 2006; Riaz, 2004)
	Wheat (8–17.5%)	–	
	Oats (8.7–16%)	–	
	Rice (7–10%)	–	
	Barley (7–14.6%)	–	
	Rye (7–14%)	–	
Quorn protein	Mycoprotein 11%	Sodium (mg) 5.0 Cholesterol (g) 0 Iron (mg) 0.5 Zinc (mg) 9.0 Selenium (μg) 20	(Finnigan *et al.*, 2019)
Bacterial protein	*Bacillus cereus* (Ram horn) 68% *Bacillus licheniformis* (Potato starch processing waste) 38% *Corynobacterium ammoniagenes* (Glucose + fructose) 61% *Escherichia coli* (Ram horn) 66% *Corynobacterium ammoniagenes* (Glucose + fructose) 61% *Cupriavidus necator* (Synthetic growth medium) 40–46%	–	(Ritala *et al.*, 2017)

good health effects on calcium metabolism and lowering cholesterol (Shih *et al.*, 2016). Moreover, soy products, such as soy flour, soy milk/powder, soy protein isolate (SPI), soy protein hydrolysates (Guo *et al.*, 2018; He *et al.*, 2019; Simmons *et al.*, 2012), could be used as food additives and nutraceutical ingredients.

Meat alternatives could be classified as plant-based (soy, gluten, pea, etc.), cell-based (vitro or cultured meat), and fermentation-based (mycoproteins) (Sha & Xiong, 2020). In recent years, plant-based meat has been developed for meeting consumer demands, exponentially grown market, and the sustainability of future food supply (Sha & Xiong, 2020). The plant-based meat market's expansion is predicted to increase from $4.6 billion in 2018 to $85 billion in 2030, and as a milestone by 2026, it would achieve $30.9 billion (Sha & Xiong, 2020). Among the several mechanistic techniques for the texturization of plant-based meat, extrusion is the most often applied one (Dekkers *et al.*, 2018).

Plant proteins represent a safe, sustainable, and practical non-pharmacological approach for lowering cholesterol. Recently, the most famous attributes of plant-based protein, that is soybean protein, is their health benefits linked to the prevention and treatment of many chronic diseases. Regular consumption of soy products reduces one's risk for chronic diseases such as cancer, heart disease, and stroke (Jooyandeh, 2011). Moreover, plant-based meat analog consumption is also beneficial in protecting against heart disease, lowering blood cholesterol; reducing the risk of cancer, and increasing bone mass (Joshi & Kumar, 2015). Furthermore, recent studies have well established that the plant-based food and beverage help in the improvement or management of immune system, have potential antimicrobial effects, helps in reducing risk of cardiovascular and gastro-intestinal diseases with improved physiological functions, decreases risk of low bone mass as well as very high levels of antioxidant activity (Paul *et al*., 2019).

In addition, high-moisture extrusion (HME), over 40% of moisture contents during processing, has the enormous advantage of lesser energy input, lower waste discharge, higher efficiency, and more excellent value of texturized products. Therefore, it is lately considered as the better choice for developing plant protein-based meat substitutes (Zhang *et al*., 2019). For texture optimization, exogenous polysaccharides are one of the functional primary additives used in food industries. At the time when proteins are denatured during the extrusion process, the dormant reactive sites of the interior proteins would become available, and the structure proteins would become flexible, which permits the protein-polysaccharide interactions. Polysaccharides could be used as cross-linker to alter the conformation of proteins, interact with proteins by cross-linking to protein side chains through Maillard reaction, and form a complex structure of protein (Caillard *et al*., 2010).

Plant-based meat analogs

Meat analog is also called meat substitute, faux meat, mock meat, or imitation meat. Analog can be defined as the compound of the same structure, such as texture, but slightly different in composition. There are two stages in the production of conventional meat analogs: preparation of emulsion and formation of its chunk. Typically, the emulsion is primed by mixing, chopping, and emulsifying proteins, fats, salts, and other inclusions to form a protein matrix. Meat analogs can be produced at low moisture (<35%) using a single screw extruder or at high moisture (>50%) using a twin-screw extruder (Lin *et al*., 2000). Moreover, Riaz (2004) described that meat analog could be formed into strips, sheets, patties, disks, and other shapes. It can absorb water at least three times its weight when cooked in boiling water for at least 15 min. The fibrous, anisotropic structure of meat analog products contributes to the meat-like feel and sensory view (Elzerman *et al*., 2013). Table 2 presents summaries of the comparison between the plant-based and animal-based alternatives to meat. Meat analogs look like textured meat and are healthy (cholesterol-free) and low-cost. In addition, mycoprotein meat analog, originated from fungus, is used as a healthy food alternative for its high-protein

Table 2. A comparison among cultured meat, plant-based meat, and animal-based meat.

	Dimension	Cultured meat	Plant-based meat	Animal-based meat	References
Background information	Origins, history, and technical operation	Idea articulated around 1930. Since 2000s, research into animal-cell culturing to produce meat.	Available in the market for several decades, made from concentrated protein- soy, wheat, pea by extrusion or coagulation.	Traditional in China, Japan, research on cell cultures for various production purposes since early 2000s.	(Bryant & Barnett, 2018; Sharma *et al*., 2015; Smetana *et al*., 2015)
	Nutritional value	Identical of regular meat.	Amino-acid profile nutritionally to meat.	Rich in protein but extraction needed due to indigestible walls.	
	Consumption and production rates and patterns	Not available in the market (optimists predict market introduction by 2019).	Established. Modest, relatively stable market share, increase since by 2010.	Products from extracted protein.	
	Position as meat alternative	Plant meats are more sustainable and animal friendly than animal-based meat.	Functional equivalent to meat.	Potentially protein-rich source for human consumption. Products rising.	
Current practice and situation	Technological	Proof of principle in 2013. Ongoing research and development.	Use of purified ingredients, increased efforts to improve meat similarity.	Growing and processing under research, have many challenges.	(Berghout *et al*., 2015; Dekkers *et al*., 2018; Osen *et al*., 2014; van der Weele *et al*., 2019)
	Lifestyle and Consumption	Proper meat produced without animal suffering.	Established as vegan alternatives replacing meat.	Novel: green product color and market profile.	
	Supporters and opposition	Attracts venture capitalists and entrepreneurs in Silicon Valley, animal welfare organizations, and other innovators. Emerging interest from meat industry.	Mix of alternative retail sector, experiments with hybrids of meat also startups and meat companies.	Pioneer companies and scientists, no consolidated coalition.	(Aiking, 2011; Aiking *et al*., 2006; Alexandratos & Bruinsma, 2012)

and low-fat content, and quality texture. The primary function of meat analogs is to replace the animal meat in the human diet. The consumers of soybean-based meat analogs include not only vegetarians but also the non-vegetarians who want to reduce their meat consumption for health reasons. For example, soybean meat analogs contain protein (50 to 95%, dry matter), and soy protein is primarily used as the protein ingredient (Chen *et al.*, 2010). Samard *et al.* (2019) demonstrated the high-moisture meat analogs are coupled with a higher integrity index and they have the stability of springiness as well as cutting strength than low-moisture meat substitute which is produced using the similar formula and screw-speed. The mechanical approaches summarized to make plant-based meat analogs are displayed in Table 3.

High-moisture extrusion of soy meat

The HME approach can be used to impart a specific texture to proteins such as soy-proteins, whey-proteins, pea-protein, or wheat-gluten (Pietsch *et al.*, 2017; Wolz *et al.*, 2016). HME is a crucial technology for transforming plant-based protein into palatable meat-like products. During the HME process, the input extruder of moisture content is more than 40%, which results in the advantages of lower energy input and higher quality of the texturized products (Zhang *et al.*, 2019). Chen *et al.* (2010) described that when moisture content of soy meat is increased from 28 to 60% (wet base), the indicator residence time and specific mechanical energy (SME) are significantly decreased. In addition, when cooking temperature is increased from 140 to 150°C, the in-line viscosity at die and SME reduced considerably, particularly at lower moisture contents (LMC). Most studies found the effects of processing parameters were done for low to moderate moisture processing. Still, these parameters can significantly affect protein structure during high-moisture processing (Palanisamy *et al.*, 2019). Due to its desirable texture and nutritional value, soy protein can be used to make soy protein products by the extrusion process (Wu *et al.*, 2019). For the traditional extrusion methods, extrusion at higher moisture conditions would reduce viscous dissipation at the lower extrusion temperature. Still, these changes would be expected during high-moisture extrusion conditions (MacDonald *et al.*, 2009). Zahari *et al.* (2020) reported the chosen parameters including concentration (0, 20, 40, 60%) of hemp protein concentrate (HPC), target moisture content (65, 70, 75%), temperature (40–120°C), and screw speed (300–800 rpm), whereas, SPI was extruded with 500 rpm at 70 and 75% of target moisture content. To summarize some literature, extrusion parameters and selected formulations of high-moisture meat analogs are shown in Table 4. MacDonald *et al.* (2009) also reported that high-moisture extrusion was useful to generate high-quality protein foods. Mechanical treatment is more effective during the high-moisture extrusion process for other plant proteins when compared with wheat gluten. Therefore, the influence of HME processing on the change of protein-protein interactions is used to form the anisotropic structures of SPIs (Chen *et al.*, 2011; Fang *et al.*, 2014).

Die-cutting

Die-cutting is a critical technology used to bring out the indentation of die-cutting of the surface to retouch the processing equipment, where this technique is a complex core unit. The die-cutting indentation position must be precise to cause simultaneously, and the complete platform stress must assure that the place of two active faces in contacts top and bottom to be mutually parallel. Shen *et al.* (2012) reported the speed of 7000 RH-1, travelling schedule 61 mm, cap board located 80°, the cam midpoint distance was 279 mm in a stand die-cutting machine. For instance, "the follower maximum pivot angle is 20°, main cam swing follower 240-mm long, roller radius 15 mm, vice-cam swing follower 240-mm long, roller radius 15 mm, the base circle initial radius is 60 mm. Moreover, the cam angle for outer dwell is 110°, the cam angle for inner dwell is 10°, work travel angle of follower is 150°, return travel angle of follower is 90°, allowed pressure angle of actuating travel is 35° allowed pressure angle of return travel is 60°, and allowable curvature radius of the real contour line of cam is 3 mm in a platform die-cutting machine (Shen *et al.*, 2012).

Table 3. Overview of mechanistic techniques to make plant-based meat analogs.

Technique	Starting material	Equipment type	Product	Process	Key technology	References
Bottom-up strategy	–	–	Structure/ structural element	–	Length scale anisotropy	(Post, 2012)
Wet spinning	Protein isolate, coagulation bath	Wet spinning setup: barrel, spinning nozzle, water bath, winding device	Fibers	–	Micrometer	(Post, 2012)

Table 4. Extrusion-parameters involved for screening and selected formulations of high-moisture meat analogs (HMMA).

Formulation	Speed of screw	Targeted moisture content (%)	Temperature (°C) (Zone 1–2–3–4)	Visual appearance color	References
0% HPC and 100% soy SPI	500	70	40–60–80–100	Light color, compact	Zahari *et al*. (2020)
	500	75		Light color, compact	
20% HPC and 80% soy SPI	800	65	40–60–80–100	Compact	Zahari *et al*. (2020)
	800	70		Compact	
	800	75		Less compact	
	600	75		Less compact	
	600	80		–	
	400	75		Less compact	
	300	75		Less compact	
40% HPC and 60% soy SPI	800	65	40–60–80–100	Compact, dark spot	Zahari *et al*. (2020)
	800	70		Compact	
	800	75		Pale, less compact	
60% HPC and 40% soy SPI	800	60	40–60–80–100	–	Zahari *et al*. (2020)
	800	62.5		–	
	800	65		Less compact	
	800	70		Less compact	
	800	75		Came out foamy	
	800	65	60–80–100–120	Less compact	

HPC: hemp protein concentrate; SPI: soy protein isolate.

Die pressure

The viscosity of the molten blend may be attributed to the decrease in pressure with the increase in temperature. The growth in feed moisture and die temperature then affects the mass thickness over the extruder and decreases the die-pressure value. Zhang *et al.* (2020a) found that the coefficient variation of the die pressure and die temperature was 26.71 and 1.74%. In addition, the measured die pressure in extrusion cooking of apple meat blend ranged from 9 to 16 MPa. The negative coefficient of the first-order term of temperature, screw speed, and moisture content indicated that die pressure increased with temperature decrease (Singha & Muthukumarappan, 2017).

High-pressure homogenization

High-pressure homogenization (HPH) is an applicable unit operation based on cavitation to improve processed soybean materials' extraction yields. Debruyne (2006) demonstrated that homogenization could cause a negative effect on separation efficiency. In addition, investigations may require evaluating the scalability of this promising result obtained by using a lab-scale homogenizer. Denaturation of the lipoxygenase occurred of enzyme high-temperature treatment may also catalyze the oxidation of polyunsaturated fatty acids, and also may also be responsible for turning into volatile off-flavors.

Characteristics of soy meat

Microstructure

Scanning electron microscopy (SEM), light microscopy (LM), Fourier transform infrared spectroscopy (FT-IR), as well as differential scanning calorimeter (DSC) are usually used to obtain more detailed information on the protein network microstructure of the meat analog. The micro-extraction technique is an environment-friendly procedure due to the reduction of polluting solvents and sample volume. For instance, the micro-extraction approach increases the extraction yield and diminishes the sample equilibrium time (Barzegar *et al.*, 2019). Micro-extraction includes several performances such as single drop micro-extraction (SDME), dispersive-liquid–liquid micro-extraction (DLLME) and hollow-fiber micro-extraction (HFLPME). Preece *et al.* (2017) reported "the cotyledon-cells protein bodies found in size range from 2.4 to 13.5 μm when used SEM approach without sample-hydration." Lakemond *et al.* (2000) described two significant storage proteins that compose 60–80% of the total soybean protein: the β-conglycinin and glycinin. Soybean protein is a complex mixture containing various proteins, and each of them has unusual denaturation temperatures. Glycinin and β-conglycinin are two main storage proteins, and their denaturation temperatures were 68 and 86°C, correspondingly (Peng *et al.*, 2016). Throughout the low moisture extrusion, the ingredients can undergo structural changes caused by high temperature and shear. It can also affect the product's characteristics, such as microstructure and expansion (Beck *et al.*, 2018).

DSC, TG and DTG measurements

The differential scanning calorimetry (DSC) analysis can be conducted with Thermal-Analysis-Systems Model Q-200. Non-isothermal degradation can be measured by using thermogravimetric/differential-thermal-analysis (TG/DTA). The thermal analysis techniques such as thermo-gravimetric-analysis (TGA) can provide information on thermal stability, including thermal-degradation of protein films. Zhang *et al.* (2020b) observed that the mixtures pass through extruder from the mixing-zone to the melting-zone for peanut protein/exogenous polysaccharide mixture, the endothermic-peaks of arachin and conarachin were both prominently reduced due to the denaturation of protein-molecules.

In the mixing zone, 2% WS (wheat starch) could cause a significant decrease in the thermal transition peak temperature (*Tp*) value and a significant increase in the enthalpy changes (ΔH) value of the conarachin. As a result, it indicated that 2% WS accelerated the thermal transition of conarachin and the energy required to open the increased molecule. Guo *et al.* (2012) described that exogenous polysaccharides had no significant effect on the ΔH value of arachin, due to the relatively tight structure of arachin. In addition, Zhang *et al.* (2020b) found that the exogenous polysaccharides had enhanced the protein-lipid interaction, when 0.1% CA or 2% WS was added. Moreover, the exogenous polysaccharides could decrease, particularly when 2% WS was added, and the value significantly reduced from 310 to 302°C.

Textural properties

There are two textural properties as the transverse (T) and directions cutting force in longitudinal (L) are positively correlated with the carrageenan (ICGN) concentration in the meat analog sample. The cutting force can also be interpreted as an indirect indicator of texturization and hardness (Palanisamy *et al.*, 2018). The elasticity differences between the raw samples containing 0.75, 1.5, and 3% ICGN were not significant, while no significant differences between all ICGN added cooked samples could be detected. Shahiri Tabarestani and Mazaheri Tehrani (2014) found that adding soy-flour, flour of split-pea, and wheat-starch could improve low-fat hamburger's texture properties by reducing shrinkage. For example, Smith *et al.* (1976) proved that the presence of textured soy protein was associated with the substantial reduction of shrinkage in the blended ground. The transversal cutting strength of texturized vegetable protein (TVP) and meat samples was slightly higher than their longitudinal cutting strength. It is stated that the cutting strength in parallel and vertical directions of extrudates could indicate the texturization degree or fibrous-structure formation (Fang *et al.*, 2014; Gu & Ryu, 2017). When SME is decreased, there is an increase in instrumental chewiness and hardness. As a result, instrumental chewiness and hardness of meat analogs increased with decreasing SPC-WG ratio (Fiorentini *et al.*, 2020). Additionally, Fang *et al.* (2014) reported that the instrumental hardness and chewiness of texturized soybean proteins increased more than 22 and 17%, respectively. Day and Swanson (2013) described that high chewiness in meat analogs corresponded with low SME values, indicative of low-melt viscosity. To summarize the literature, common soy meat analogs available in the market are presented in Table 5, which were both prominently reduced due to the denaturation of protein molecules.

Anti-nutritional factors

A wide variety of anti-nutritional substances are available in most of the potential and alternative plant-derived nutrient sources. Metabolic products arising in living systems may be defined as anti-nutrient substances that affect health or food production by themselves or through their food utilization. Anti-nutritional substances could be usually divided into four groups: (1) factors that affect mineral utilization, including gossypol pigments, phytates (Hexa-phosphates of Myo-inositol), oxalates and glucosinolates, (2) factors that affect protein utilization and digestion, including lectins, protease inhibitors and tannins, (3) Anti-vitamins, (4) Miscellaneous substances for example, mycotoxins, cyanogens, mimosine, alkaloids, nitrate, phytoestrogens, photosensitizing agents, and saponins.

Besides, Ma *et al.* (2020) recounted those anti-nutritional compounds that reduced the bio-availability of the essential nutrients or energy in the diet. Reducing the content of the anti-nutritional factors (ANFs) can efficiently improve the use of soy nutrients. Based on protein content, products from soy-protein are divided into three broad categories: (1) soy flour and grits (50% protein on a moisture-free basis); (2) soy protein concentrates (70% protein), and (3) isolated soy proteins (90% protein) reported by Singh *et al.* (2008). In addition, Thadavathi *et al.* (2019) reported that the high protein vegetable-based foods were used as an alternative for meat products which was enormously advantageous for the increasing human population in the world, and it could address the environmental concerns as well as the health considerations from meat consumption. Moreover, Aijie *et al.* (2014) reported that the ANFs decreased during germination, which was attributed to the activation of several enzymes in the seed. The summarized literature on anti-nutrients and ANFs of soybean are presented in Table 6.

Allergenic protein

There are many kinds of allergenic compounds and ANF's present in soybean. According to the report of food allergens, almost 2% of adults and 5–8% of children have food allergic reactions associated with the consumption of soybean or soybean derived food products (John *et al.*, 2017). Additionally, Gagnon *et al.* (2010) reported that food allergies are a big concern for health in most countries. In addition, allergic reactions to food affect 4–6% of children and 1.5% of adults (Uguz *et al.*, 2005). There are different allergenic proteins present in soybeans. However, soybean proteins allergic reactions are mostly transient and non-life-threatening and are usually outgrown after 3 years of age. It seems to be tolerant within 2–5 years after the initial diagnosis. Soybean allergenic proteins can be detecting to soybean allergens. In recent years, researches about allergenic soybean proteins detection have been rapidly expanded. Currently using two most approaches

Table 5. Common soybean meat analogs existing in market.

Name of product	Introduction/first reported	Main ingredients/origin	Characteristics/remarks	References
Tofu	China	Pressed soy curd prepared from coagulated soy.	Most widely recognized meat alternatives, blind taste, can impart flavor by smoking/marinating.	(Sadler, 2004)
Tivall	1997	Soy-based fibrous vegetable protein.	Simulate meat muscle, provide a different eating textures to other soy formats.	(Sadler, 2004)
Tempeh	1851 in Indonesia	Fermented soy-based cake.	Controlled fermentation of soy leads, similar shape to burger patties.	(Kumar *et al.*, 2017; Malav *et al.*, 2015)
Grillers original burgers		Extruded vegetable protein burgers.	Veggie goodness, soy protein concentrate, water for hydration.	(Kyriakopoulou *et al.*, 2019)
Schnitze		Rehydrated soy protein products.	–	(Kyriakopoulou *et al.*, 2019)

Table 6. Comparison of the soybean and other grains substitute of anti-nutritional factors and fractions.

Plant substitutes	Anti-nutritional factors				References
Soybean meal	Protease inhibitors, saponins, anti-vitamins , phytic acid, lectins, phytoestrogens and allergens.				(Francis *et al.*, 2001)
Rapeseed meal	Rapeseed meal, protease-inhibitors, phytic acid glucosinolates and tannins.				
Pea seed meal	Pea seed protease-inhibitors, tannins, lectins, cyanogens and phytic acid.				
Sesame meal	Sesame phytic acid and protease inhibitors.				
Cottonseed meal	Cottonseed meal phytic-acid, phyto-estrogens, gossypol and anti-vitamins.				
Various grains	**Grains fractions**	**Arabinoxylans**	**β-Glucans**	**Cellulose**	
Soybean	Soluble	–	–	–	(Choct, 1997)
	Insoluble	–	–	4.4%	
Wheat	Soluble	1.8%	0.4%	–	
	Insoluble	6.3%	0.4%	2%	
Barley	Soluble	0.8%	3.6%	–	
	Insoluble	7.1%	0.7%	3.9%	
Maize	Soluble	0.1%	–	–	
	Insoluble	5.1%	–	2%	
Sorghum	Soluble	0.1%	0.1%	–	
	Insoluble	2%	0.1%	2.2%	

like Enzyme linked immunosorbent assays (ELISA) and Immunoblotting, also using by Radio allegro-sorbent test inhibition, Enzyme allego-sorbent test, Polymerase chain reaction, Mass spectrometry, High-performance liquid chromatography (Wang *et al.*, 2014). ELISA is a powerful tool for detecting proteins, ELISA such as Sandwich ELISA, Competitive ELISA and Indirect ELISA are widely used to determine soybean proteins in food products (Wang *et al.*, 2014). Immunoblotting is a powerful research tool which can indicate molecular mass and immunoreactivity of allergenic proteins. Beardslee (2000) found soybean allergenic proteins glycinin G1 acidic chain and a 22 kDa G2 glycinin by using immunoblotting.

Sensory evaluation

The mouthfeel and fibrousness are the same as meat, which are the primary sensory properties to consider when consuming the meat alternatives. The addition of IoT-carrageenan (ICGN) concentration is essential to increase the fibrousness of the product because of its denser structure. Palanisamy *et al.* (2018) observed extra 2.25 to 3% ICGN can increase elasticity which could be detected significantly with the overall scores' acceptance ranged from 1.73 to 2.49%. The ICGN concentration was positively correlated with the fibrousness; the hardness could also be influenced by the preference (Palanisamy *et al.*, 2018). Cheftel *et al.* (1992) reported that texturization with HME is entirely different from other protein texturization processes such as manufacturing cheese curds, sausages, tofu, in which fiber was formed by extrusion cooking or by spinning. In addition, proteins would be plasticized in the heating chamber during the extrusion process of texturizing a long cooling die at the end. The process could be optimized by varying the temperature, moisture, pressure, and shear.

Health characteristics of soybean

Regular consumption of soy products can reduce the risk of chronic diseases such as cancer, stroke, heart disease, and type 2 diabetes (Jooyandeh, 2011). Soy-based foods also provide beneficial health compounds, including vitamins, minerals, fiber, and flavonoids. In addition, various clinical trials have investigated the potential of soybean and soybean products to protect against the risk of chronic diseases. Furthermore, Scheiber *et al.* (2001) described soybean consumption as reducing the risk of cardiovascular disease. Recently, pea protein is used as an alternative ingredient in high-moisture meat analogs because of its functional characteristics and low potentiality for allergic responses (Osen *et al.*, 2014). Akdogan (1999) reported that protein and other food additives, such as starch or lipid, probably have a positive or negative effect on forming the desired texture. Furthermore, Asgar *et al.* (2010) reported that other types of legumes and oilseeds could also be used as protein-rich materials to develop a variety of high-moisture meat analogs, which could contribute to alternative protein sources.

Market potential alternate plant proteins

In contemporary years, plant-based proteins have received increasing attention as good substitutes for animal-based proteins. The important reasons for the increasing acceptability of plant-based protein are the low cost and fibrous texture (Echeverria-Jaramillo *et al.*, 2021). Plant-based protein's growing trend is setting out to increase the number of vegetarians or meat avoiders (Aschemann-Witzel *et al.*, 2021). Proteins, in particular, plant-based proteins are more important in the face of future challenges, ensuing from unceasing population growth and the unevenness between malnutrition and overweight/obesity (Mittermeier-Kleßinger *et al.*, 2021). Time trends for the development of alternative protein ingredients are demonstrated in Table 7. The key drivers of market growth include: (1) consumers concern over food safety in relation to animal products; (2) growth in the number of vegetarians, meat avoiders, and meat reducers; (3) meat eaters seeking more variety in their diet; (4) growing interest in healthy eating which includes incorporating more plant-based foods into the diet.

Conclusion

This review concluded that high-pressure extrusion is an effective technology that can potentially be used to produce natural food products in which heat treatment will be reduced. This enhances the hydrophobic interactions and increases the visible viscosity to stabilize the newly formed conformation of the texturized effects. Plant proteins have some physiologically active components such as protease phytosterols, inhibitors saponins, and isoflavones. The thermo-mechanical treatment affects the microstructural changes and the rheological properties in SPC during high-moisture extrusion processing. Therefore, the importance of soybean meat analog products as an alternative soy meat source that should be explored along with studies to clarify the underlying effects of the quality and increasing acceptability of plant-based protein are the low cost and fibrous texture. Future study are required on protein-extraction yield and purification which could be predicted well using another mechanistic model developed as well as on flavor and texture meat analog products.

Table 7. Time-trends for development of alternative protein ingredients.

Protein ingredients	Approx. year introduced	References
Nuts	Increased imports post 1945 Soy	(Sadler, 2004)
Quorn™ (mycoprotein)	1984	
WheatPro™ (wheat protein)	1992	
Arrum™ (wheat and pea protein)	1995	
Fibrous vegetable protein	1997	

Acknowledgement

This work was supported by the China Agriculture Research System (CARS-04) and the Knowledge Innovation Program Funding of the Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences (125161015000150013), "the Science and Technology Innovation Project" of the Chinese Academy of Agricultural Sciences (CAAS-ASTIP-2020-IFST-04). The first author gratefully thanks the Chinese Scholarship Council for providing a full scholarship to study PhD at the Graduate School of Chinese Academy of Agricultural Sciences, Beijing, China.

Conflicts of interest

There is no conflict of interest exit to the submission of this manuscript. This manuscript is approved by all authors for publication.

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